

Our File No. 9281-4722
Client Reference No. SK US02016

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTORS: Munemitsu Abe
Yoshihiro Someno
Masayoshi Esashi

TITLE: Functional Multilayer Film And
Method For Manufacturing The
Same

ATTORNEY: Gustavo Siller, Jr.
BRINKS HOFER GILSON & LIONE
P.O. BOX 10395
CHICAGO, ILLINOIS 60610
(312) 321-4200

EXPRESS MAIL NO. EV 327 136 800 US

DATE OF MAILING 12/3/03

FUNCTIONAL MULTILAYER FILM AND METHOD FOR MANUFACTURING THE
SAME

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

This invention relates to a functional multilayer film having fine metallic bodies dispersed in a dielectric substance, and more specifically, to a functional multilayer film in which the size of metal bodies is made substantially
10 uniform and the fine metallic bodies are arranged regularly in the thickness direction and the surface direction.

Conventionally, an optical material fixed by dispersing fine metallic bodies in a dielectric substance is used as the optical material showing a nonlinear optical effect. It is
15 possible for such an optical material to vary the reflection or diffraction of incident light by providing potential difference, otherwise oppositely to vary the electric field in the substance by making light incident thereon. Using such characteristics, the optical material showing the
20 nonlinear optical effect can be used in the optical communication field, or all of optical calculating elements, etc.

The characteristics of the optical material vary depending on the size or arrangement of fine metallic bodies
25 dispersed in a matrix made of a dielectric substance. Accordingly, in order to manufacture an optical material having a desired function, the fine metallic bodies must have a predetermined size or be arranged in a predetermined

pattern. Preferably, fine metallic bodies in a dielectric matrix have the same size, as much as possible, and the particles thereof are dispersed in uniform density. Moreover, the fine metallic bodies can have a desired characteristic by
5 having a specific arrangement.

The optical material showing such a nonlinear optical effect, as disclosed in US Patent No. 5,906,670, is manufactured by making metallic fine particles included in a solution containing polymer, etc., removing a volatile
10 solvent from the solution, and forming a dielectric matrix in which metallic fine particles are enclosed. In this case, the metallic fine particles are randomly dispersed in the dielectric matrix.

However, the conventional optical material showing the
15 nonlinear optical effect had the following problems.

In case that the metallic fine particles are randomly dispersed in a dielectric substance, it is impossible to arrange the metallic fine particles regularly, and a partial irregularity in the density of the metallic fine particles
20 occurs easily. Moreover, since metallic fine particles are diffused into a dielectric substance, the particles may become large and the size of particles may become unstable due to a granulation effect in case that the dispersion density of the fine metallic particles is large. It was
25 impossible to obtain an excellent nonlinear property with the conventional optical material due to the irregularity in the distribution of the particles or unstableness in the size of the particles, as described above.

Thus, a functional multilayer film has been proposed wherein dielectric thin films 2 are laminated to form a matrix 1, and a number of fine metallic bodies 4 are arbitrarily arranged on a surface 3 of each of the dielectric thin films 2 thereby to form a metal pattern 5.

According to this functional multilayer film, it is possible to arrange fine metallic bodies 4 at a predetermined interval. This enables the local unevenness of the fine metallic bodies 4 in the matrix 1 to be suppressed.

10

SUMMARY OF THE INVENTION

However, according to this functional multilayer film, the intervals of the fine metallic bodies 4 in the thickness direction of film and the arrangement thereof in the surface direction of film can be regular, but it is difficult to make the fine metallic bodies 4 arranged in each layer in the surface direction of film to be aligned also in the thickness direction of film. In other words, as can be also found from Fig. 7, it is difficult to arrange fine metallic bodies 4 of a dielectric thin film 2b directly on fine metallic bodies 4 of a dielectric thin film 2a. As a result, the fine metallic bodies 4 are not arranged in line with respect to the thickness direction of film.

The present invention was made to solve the above problems. It is therefore an object of the present invention to provide a functional multilayer film and a method for manufacturing the same wherein the intervals of the fine metallic bodies in the thickness direction of film and the

arrangement thereof in the surface direction of film are regular, and the fine metallic bodies arranged in each layer in the surface direction of film are aligned in the thickness direction of film.

5 In order to solve the above problems, a functional multilayer film according to the present invention is obtained by fixing a plurality of fine metallic bodies to a matrix made of a dielectric substance, the matrix is obtained by laminating metal-arranged thin films, each metal-arranged
10 thin film comprising a dielectric thin film having a predetermined thickness and the fine metallic bodies arranged in the dielectric thin film, and a plurality of recesses is regularly formed on the surface of the dielectric thin film, and the fine metallic bodies are arranged in the lower parts
15 of the recesses.

According to the present invention, the intervals of the fine metallic bodies in the thickness direction of film and the arrangement thereof in the surface direction of film can be regular, and the fine metallic bodies arranged in each
20 layer in the surface direction of film can be aligned in the thickness direction of film.

Further, in the functional multilayer film according to the present invention, the dielectric thin films and the fine metallic bodies are made of different materials in every
25 metal-arranged thin film or in every region including a plurality of the metal-arranged thin films.

According to the present invention, by making the dielectric thin films or the fine metallic bodies to be made

of different materials each other, it is possible to give one functional multilayer film a complex functional effect.

Further, a method for manufacturing a functional multilayer film according to the present invention comprises the steps of: forming a dielectric thin film so as to have a plurality of recesses regularly arranged on the surface thereof, forming a metal-arranged thin film by forming a metallic thin film on the dielectric thin film, and performing a heat treatment to the metallic thin film so as to flow metal into the lower parts of the dielectric thin films to form fine metallic bodies, and forming a matrix by laminating a plurality of the metal-arranged thin films, each comprising the dielectric thin film and the minute metallic bodies.

According to the present invention, it is possible to manufacture a functional multilayer film wherein the intervals of the fine metallic bodies in the thickness direction of film and the arrangement thereof in the surface direction of film is regular, and the fine metallic bodies arranged in each layer in the surface direction of film are aligned in the thickness direction of film

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view schematically illustrating a functional multilayer film according to a first embodiment;

Fig. 2 is a schematic cross-sectional view of the functional multilayer film according to the first embodiment;

Fig. 3 is a schematic cross-sectional view illustrating

manufacturing processes of a functional multilayer film;

Fig. 4 is a schematic cross-sectional view of a functional multilayer film according to a second embodiment;

Fig. 5 is a schematic cross-sectional view of a functional multilayer film according to a third embodiment;

Fig. 6 is a schematic cross-sectional view of a functional multilayer film according to a fourth embodiment; and

Fig. 7 is a schematic cross-sectional view of a functional multilayer film proposed by the present inventors.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. First, a first embodiment will be explained. Fig. 1 is a perspective view schematically illustrating a functional multilayer film according to the first embodiment. Also, Fig. 2 is a schematic cross-sectional view of the functional multilayer film according to the first embodiment.

The functional multilayer film according to this embodiment comprises a matrix 1 obtained by forming a dielectric thin films 2 made of a dielectric substance on a substrate 9, arranging a number of fine metallic bodies 4 on each of the dielectric thin films 2 so as to form a metal-arranged thin films 6, and laminating a plurality of the metal-arranged thin films 6. SiO_2 , etc may be used as a material of the dielectric thin films 2. Further, Au, etc., may be used as a material of the fine metallic bodies 4.

Fig. 2 is a cross-sectional view of the matrix 1 formed as described above. As shown in Fig. 2, each of the dielectric thin films 2 has a plurality of conical recesses 3a having the same shape which is regularly arranged on a surface 3 thereof, and has substantially spherical fine metallic bodies 4 arranged in the lower parts of the conical recesses 3a so as to form a metal-arranged thin film 6. Although the fine metallic bodies 4 are formed in a substantially spherical shape herein, the shape of the fine metallic bodies 4 is not limited thereto.

By laminating a plurality of the metal-arranged thin films 6, each comprising a dielectric thin film and the fine metallic bodies 4, a matrix 1 is formed. The number of dielectric thin films 2 is five (i.e. dielectric thin films 2a to 2e) herein, and the respective dielectric thin films 2a to 2e are formed to have the substantially same thickness. However, the number of the dielectric thin films 2 to be laminated is not limited thereto.

Further, conical recesses 3a of the dielectric thin film 2b are formed in the same shape on conical recesses 3a of the dielectric thin film 2a. Similarly, conical recesses 3a of an overlying dielectric thin film 2c are formed in the same shape on conical recesses 3a of an underlying dielectric thin film 2b.

As described above, by arranging substantially spherical fine metallic bodies 4 in the lower parts of a plurality of the conical recesses 3a which is regularly arranged on the surface 3 of each of the dielectric thin films so as to form

the metal-arranged thin film 6, and laminating a plurality of the metal-arranged thin films 6, it is possible to arrange the fine metallic bodies 4 at the substantially same intervals in the thickness direction of film and in the surface direction of film. As a result, it is possible to suppress a partial irregularity in the thickness direction of film and in the surface direction of film compared with a case in which metallic fine particles are randomly arranged in a dielectric matrix.

Moreover, by forming conical recesses 3a of an overlying dielectric thin film 2b in the same shape on conical recesses 3a of an underlying dielectric thin film 2a, the fine metallic bodies 4 arranged in the lower parts of the conical recesses 3a are aligned in the direction of the film thickness.

Furthermore, although the recesses 3a are formed in a conical shape herein, the shape of the recesses 3a is not limited thereto, but may be formed, for example, in a quadrangular pyramidal shape or a triangular pyramidal shape. Further, the recesses are not limited to the conical shape, but may be formed in a cylindrical shape, semispherical shape, or a square shape.

Next, a method for manufacturing such a functional multilayer film will be described. Fig. 3 is a schematic cross-sectional view illustrating manufacturing processes of a functional multilayer film. First, a substrate 9 having a plurality of conical recesses 9a of the same shape regularly arranged is prepared. The substrate 9 can be formed by

performing an etching process to a thin plate made of Si.
The dielectric thin film 2a is formed to have a predetermined thickness on the substrate 9 (Fig. 3A). By forming the dielectric thin film 2a on the substrate 9 so as to have the
5 conical recesses 9a in this manner, it is possible to form a plurality of conical recesses 3a of the same shape regularly arranged on the surface 3 of the dielectric thin film 2a.

Next, a metallic thin film 4a is formed on the dielectric thin film 2a (Fig. 3B), and the metallic thin film
10 4a is subjected to a heat treatment after forming the film (Fig. 3C). When heat is applied to the metallic thin film 4a, a metal constituting the metallic thin film 4a is melted to have fluidity, and then is collected in the lower parts of the conical recesses 3a along an oblique plane of each of the
15 conical recesses 3a. Then, by further applying heat to the melt, it aggregates and forms substantially spherical, fine metallic bodies 4 (Fig. 3D). The fine metallic bodies 4 are arranged in the lower parts of the respective conical recesses 3a in this manner, consequently, a metal-arranged
20 thin film 6 is formed.

Then, by repeatedly performing a process in which the dielectric thin film 2b is further formed to have a predetermined thickness on the metal-arranged thin film 6 (Fig. 3E), and a metallic thin film 4a is formed so as to
25 form fine metallic bodies 4, a matrix 1 having a plurality of the metal-arranged thin films 6 laminated therein is formed. In this manner, by forming a further overlying dielectric thin film 2a on the dielectric thin film 2 having the conical

recesses 3a, it is possible to form conical recesses 3a of an overlying dielectric thin film 2a on conical recesses 3a of an underlying dielectric thin film 2a thereof.

Moreover, the film can be formed by using a sputtering
5 method, a chemical deposition method (CVD), etc.

Although the fine metallic bodies 4 are aggregated to form a substantially spherical shape in this embodiment, a heat treatment may be completed prior to the aggregation so as to form the fine metallic bodies 4 in the same shape as
10 the bottoms of the conical recesses 3a.

Furthermore, by forming the conical recesses 3a in the form of recesses having an elliptical section, forming the fine metallic bodies 4 in the same shape as the conical recesses 3a, and providing the shape of the fine metallic
15 bodies 4 with directionality, the fine metallic bodies 4 may have an anisotropic property with respect to a polarized direction.

Next, a second embodiment will be explained. Fig. 4 is a schematic cross-sectional view of a functional multilayer
20 film according to this embodiment. The functional multilayer film of this embodiment has a plurality of conical recesses 3a with the same shape which is regularly arranged on a surface 3 of a dielectric thin film 2, and is configured by laminating metal-arranged thin films 6, which are
25 respectively obtained by arranging a plurality of substantially spherical fine metallic bodies 4 in the lower parts of the conical recesses 3a. In the first embodiment, the fine metallic bodies 4 are arranged at substantially

regular intervals in the thickness direction of film.
However, the fine metallic bodies does not need to be
arranged at regular intervals, and the dielectric thin film 2
can be formed such that the fine metallic bodies are arranged
5 at arbitrary intervals.

As shown in Fig. 4, in this embodiment, the film
thicknesses of the dielectric thin films 2 are not regular,
but the dielectric thin films are formed so as to have an
arbitrary thickness, respectively. That is, in Fig. 4,
10 dielectric thin films 2c and 2d are made thicker than the
other dielectric thin films 2a, 2b, and 2e. The second
embodiment is similar to the first embodiment in that the
dielectric thin film 2 has a plurality of conical recesses 3a
with the same shape which is regularly arranged on the
15 surface 3, and substantially spherical fine metallic bodies 4
are formed in the lower parts of the conical recesses 3a. By
laminating the dielectric thin films 2 whose thickness are
different from each other, as mentioned above, the fine
metallic bodies 4 have an arrangement pattern in the
20 thickness direction of film. Accordingly, the functional
multilayer film enables a desired nonlinear optical effect to
be obtained.

Next, a third embodiment will be explained. Fig. 5 is a
schematic cross-sectional view of a functional multilayer
25 film according to this embodiment. The functional multilayer
film of the embodiment has a plurality of conical recesses 3a
with the same shape which is regularly arranged on a surface
3 of a dielectric thin film 2, and is configured by

laminating metal-arranged thin films 6 obtained by arranging a plurality of substantially spherical fine metallic bodies 4 in the lower parts of the conical recesses 3a. As a result, it is possible to make the materials of the dielectric thin films 2 or the materials of the fine metallic bodies 4 to be different for every metal-arranged thin film 6.

In this embodiment, dielectric thin films 2c and 2d and the other dielectric thin films 2a, 2b, and 2e are made of different materials. Further, fine metallic bodies 4 arranged on the dielectric thin films 2c and 2d and fine metallic bodies 4 arranged on the dielectric thin films 2a, 2b, and 2e are made of different materials. By making the materials of dielectric thin films 2 or fine metallic bodies 4 of the metal-arranged thin film 6 to be different from each other, one functional multilayer film may have a complex function.

Next, a fourth embodiment will be explained. Fig. 6 is a schematic cross-sectional view of a functional multilayer film according to this embodiment. In this embodiment, it is configured such that multilayer film filters 7a and 7b are provided at the end of the matrix 1 in the thickness direction of film. That is, a functional multilayer film region 8, which is obtained by laminating dielectric thin films 2 and a substrate 9, is interposed between the multilayer film filters 7a and 7b. The multilayer film filters 7a and 7b function as a so-called narrow bandwidth reflection filter, which transmits only a light component with a specific wavelength. This configuration enables a

light component with a specific wavelength to travel back and forth through the functional multilayer film region 8 several times by a reflection mirror effect of the multilayer film filters 7a and 7b. This enables a nonlinear optical effect on the incident light to be controlled. Moreover, although it is configured herein such that the functional multilayer film region 8 is interposed between the multilayer film filters 7a and 7b, the functional multilayer films 2 may have a functional multilayer filter therebetween.

Since the reflection or transmission of light can be controlled by means of the electric field in the functional multilayer film region 8, it is possible to control the nonlinear optical effect by providing an electrode (not shown) in the functional multilayer film region 8 and thereby repeating the reflection of a light component with a specific wavelength several time as described above. Further, by making light incident on the functional multilayer film region 8, the electric field in this region varies. Accordingly, when a light component with a specific wavelength of light to be transmitted exists in the functional multilayer film region 8, another controlled light component is entered to the region to vary a state of electric field, and thus it is possible to reflect the specific wavelength of light in the region. This enable an optical switch controlled by light to be configured.

According to the present invention as described above, fine metallic bodies are arranged in the lower parts of a plurality of recesses which is regularly arranged on a

surface of a dielectric thin film so as to form a metal-
arranged thin film, and a plurality of the metal-arranged
thin films are laminated. Thus, the intervals of the fine
metallic bodies in the thickness direction of film and the
5 arrangement thereof in the surface direction of film become
regular. As a result, it is possible to suppress a partial
irregularity in the fine metallic bodies in the thickness
direction and surface direction of film. Moreover, it is
possible to make the fine metallic bodies arranged in the
10 lower parts of the recesses of each layer in the surface
direction of film to be aligned in the thickness direction of
film. This enables a functional multilayer film having an
excellent nonlinear property to be obtained. Further, it is
also possible to arbitrarily control an interaction between
15 layers of the fine metallic bodies aligned in the thickness
direction of film.

Further, according to the present invention, the
dielectric thin films and the fine metallic bodies are made
of different materials in every metal-arranged thin film or
20 in every region including a plurality of the metal-arranged
thin films. As a result, one functional multilayer film may
have a complex functional effect.

Further, according to the present invention, a
dielectric thin film is formed to have a plurality of
25 recesses regularly arranged on the surface thereof, a
metallic thin film is formed on the dielectric thin film, a
heat treatment is performed to the metallic thin film for
metal to flow into the lower parts of the recesses of the

dielectric thin film so as to form fine metallic bodies to complete a metal-arranged thin film, and a plurality of the metal-arranged thin films is laminated to form a matrix. As a result, it is possible to manufacture a functional

5 multilayer film in which the intervals of the fine metallic bodies in the thickness direction of film and the arrangement thereof in the surface direction of film are regular, and the fine metallic bodies arranged on each layer in the surface direction of film are aligned in the thickness direction of

10 film.